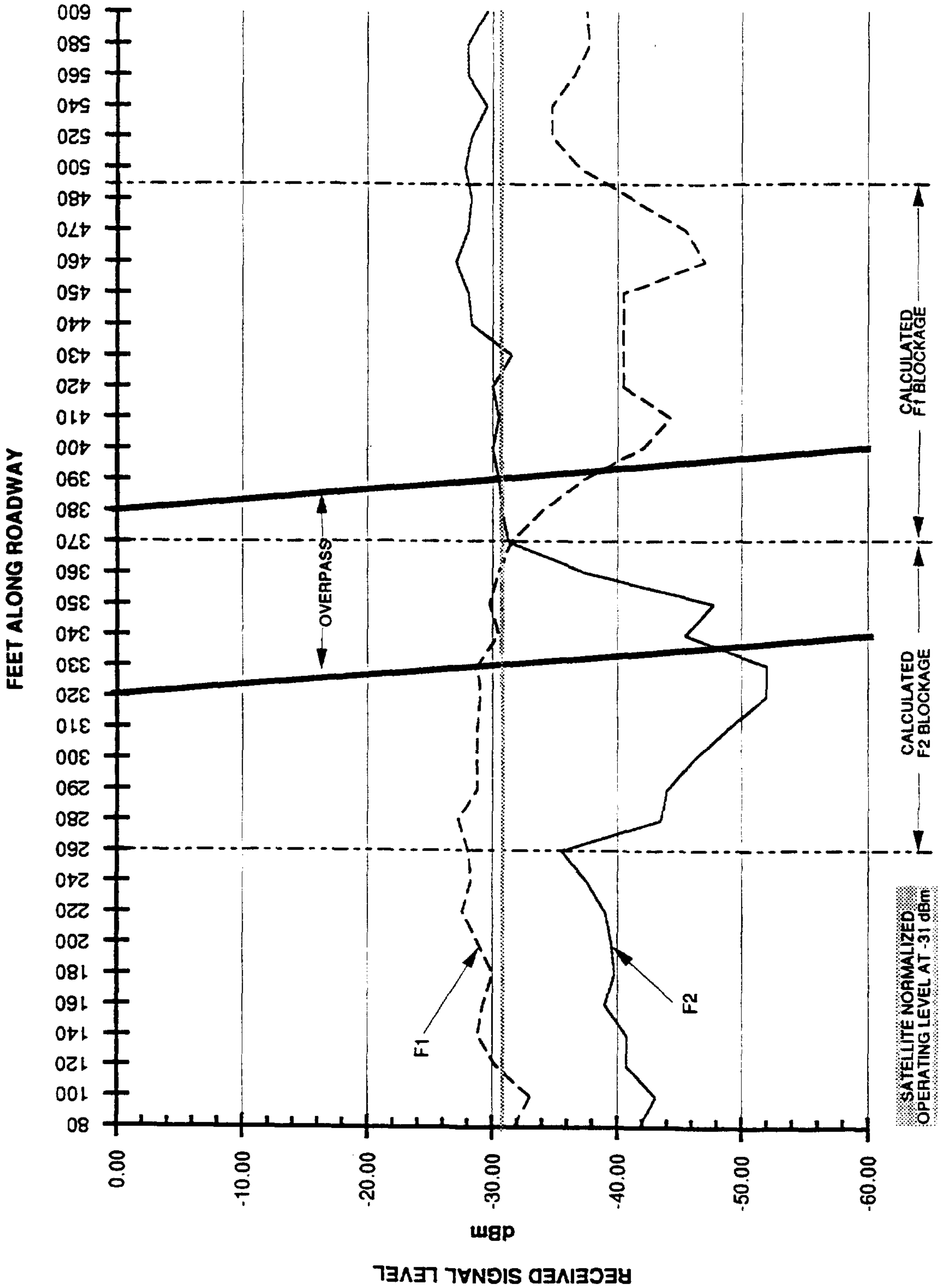
Figure A1-2 Highway Overpass, Test Results Summary



Accuracy

The accuracy of the measured data after reduction and calibration is ± 0.7 dB in signal level and ± 5 feet in drive range. However, it is important to note that the physical closeness of the satellite transmitters to the overpass creates a change in signal strength with range. Doubling the range reduces the received transmitter power by 6 dB. Combined with this, to achieve uniform power in the area of the overpass, the satellite transmitters used sector coverage antennas. These antennas affect the data accuracy only in the drive range areas of 80-120 and 540-600 feet. Generally, the other antenna pattern effects were calibratable.

A1.2 MULTIPATH FADING AND BLOCKAGE

Objectives

The main objectives were to demonstrate the effectiveness of spatial diversity to reduce significantly the effects of outages due to blockage and to demonstrate the effectiveness of combined spatial and frequency diversity to reduce significantly the effects of multipath in a typical urban/suburban environment of a satellite DARS system. The use of satellite spatial and frequency diversity in a DARS system is fully described in Appendix B "CD RADIO DARS TECHNOLOGY INNOVATIONS" which is submitted to the FCC concurrently with this report.

Implementation

The basic implementation is described elsewhere in the report, particularly in the portions dealing with the Test Range and vehicle instrumentation. Extensive measurements were performed on the Test Range of both multipath and blockage mitigation. Measurements were also performed on Pennsylvania Avenue, across the street from CD Radio's programming/uplink earth station. These later measurements consisted of sending two modulated S-band transmissions at different radio frequencies in the 2310-2360 MHz band from the rooftop at 1001 22nd Street, N.W. to the test vehicle. The elevation angle from the vehicle to the rooftop was 19^{o} and no spatial diversity was employed.

Measurements

Figure A1-3 best summarize the measurement data as recorded by the earlier described automatic data collection subsystem. The Figure essentially shows the measured signal strength throughout the Test Range as received by each of the four receivers. The positions of the measurements are shown accurately in Figures A1-4. The measured signal strengths shown in Figure A1-3 are referred to an AGC value of 190 which is the calculated operating point of the CD Radio satellite DARS system. This will be further discussed under later sections but it is necessary to regard the measured data as worst case since, as was shown in Figure A2-2, complete coverage of the drive path in Figure A1-4 by two transmitters above 10° elevation was not available over certain portions of the drive path (i.e., the drive path exceeded in places the Test Range so sensitivity limitations could be assessed).

A second set of measurements was directed at isolating to the extent possible the effect of frequency selective fading. Figure A1-5 is representative of frequency selective fading. These data were taken on the special range earlier described without spatial diversity at 3:00 PM on May 10 as measured at the L-band down converted vehicle receiver output where both S-band modulated carriers could be plotted. The carriers are spaced 10 MHz apart. Essentially, broad frequency selective variations ranging from 3-5dB were common. However, occasional deep fades occurred both narrow in spectrum as shown in Figure A1-6, at 3:51:00 PM on May 19 and broad, (i.e., greater than 5 MHz) in spectrum. Good illustrations of these are also shown in Figure A1-7. Figure A1-7 was taken on the Test Range with 8 MHz S-band carrier spacing. Broad frequency selective fades as large as 25-30 dB were infrequently observed. Figure A1-8 is an expanded plot of a moderately deep narrow frequency selective fade.

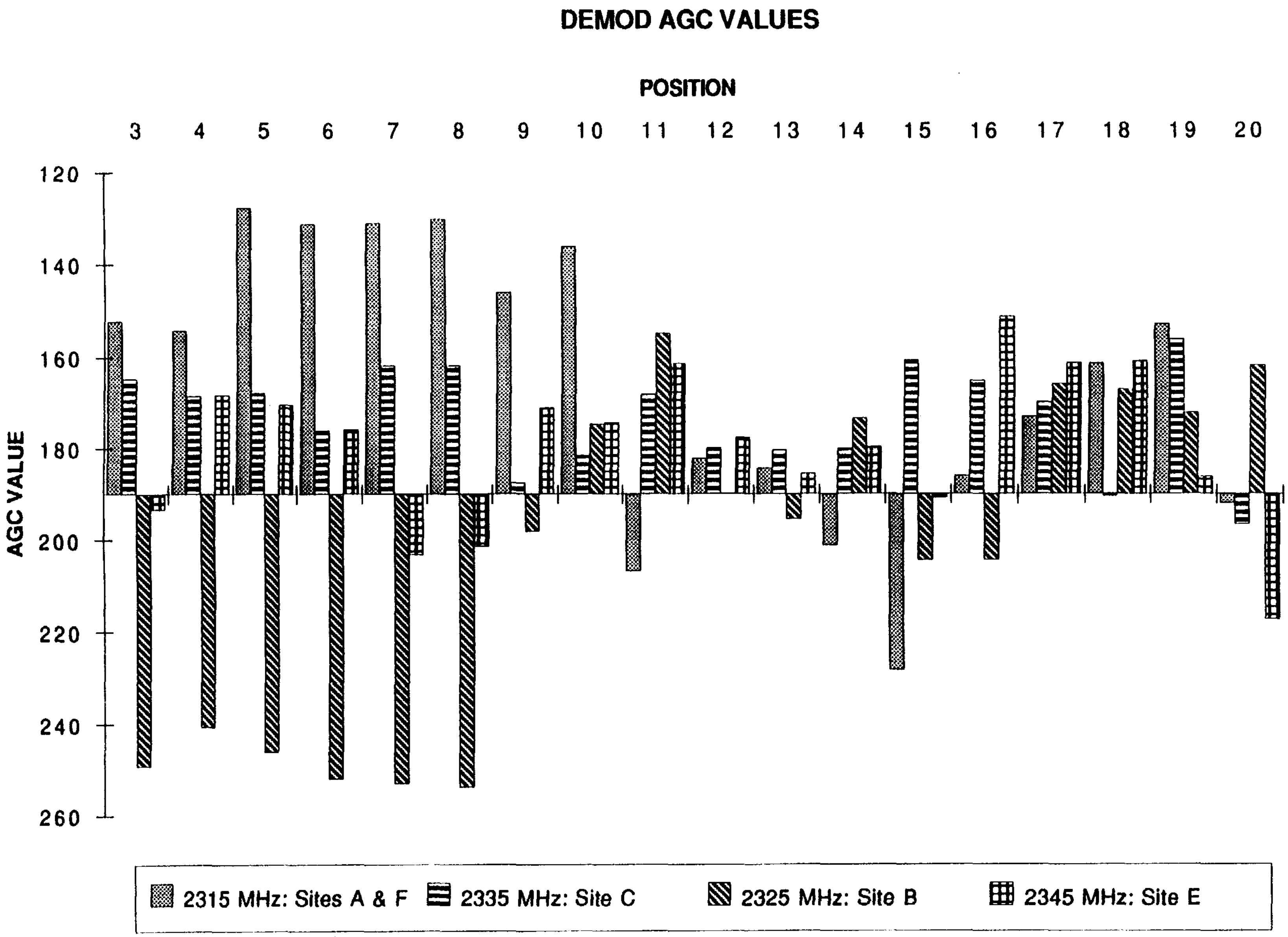


Figure A1-3 Test Range AGC Measurements - Sheet 1 of 2

CD RADIO INC.

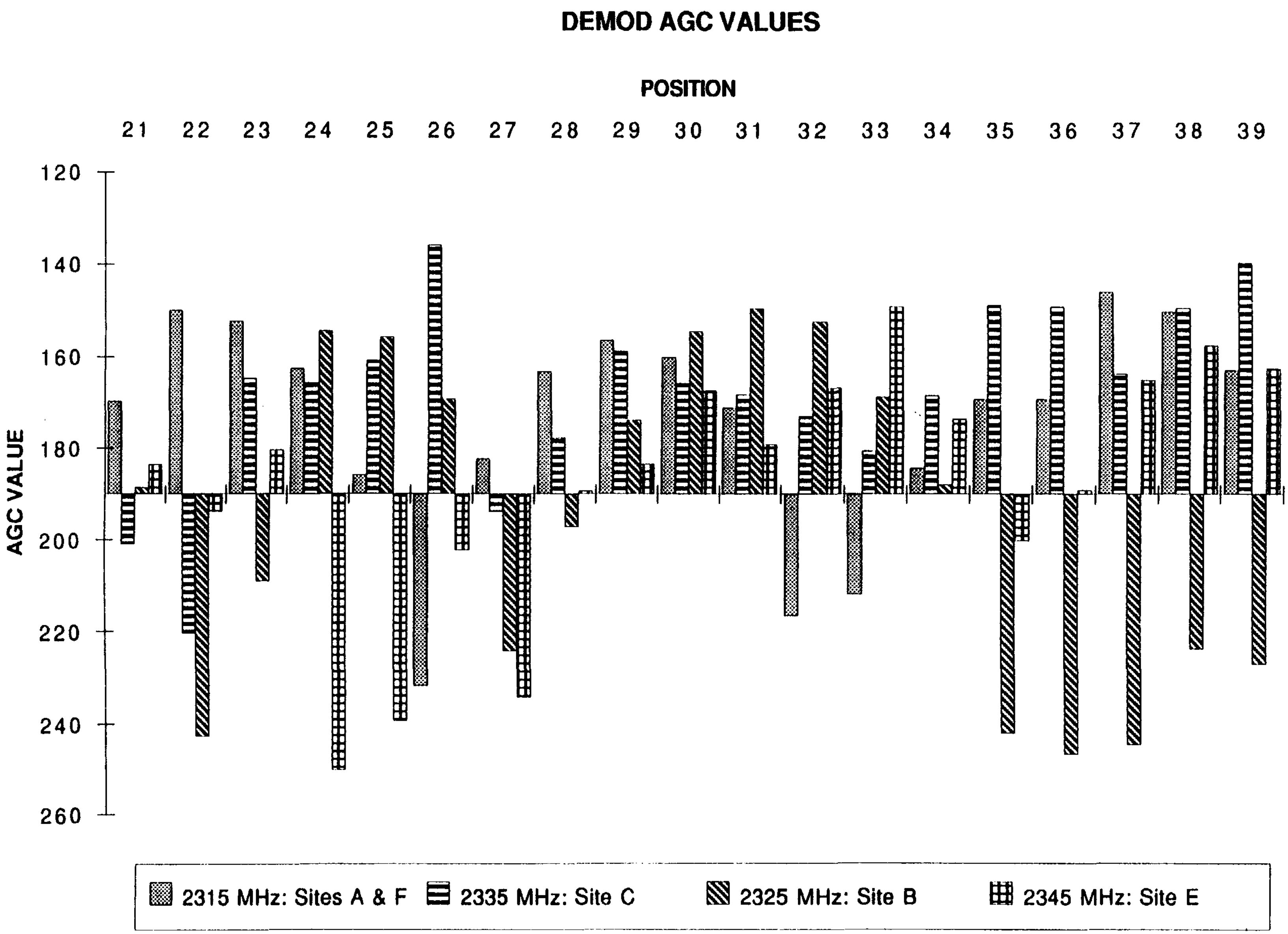


Figure A1-3 Test Range AGC Measurements - Sheet 2 of 2

Figure A1-4 Test Range Measurement Points

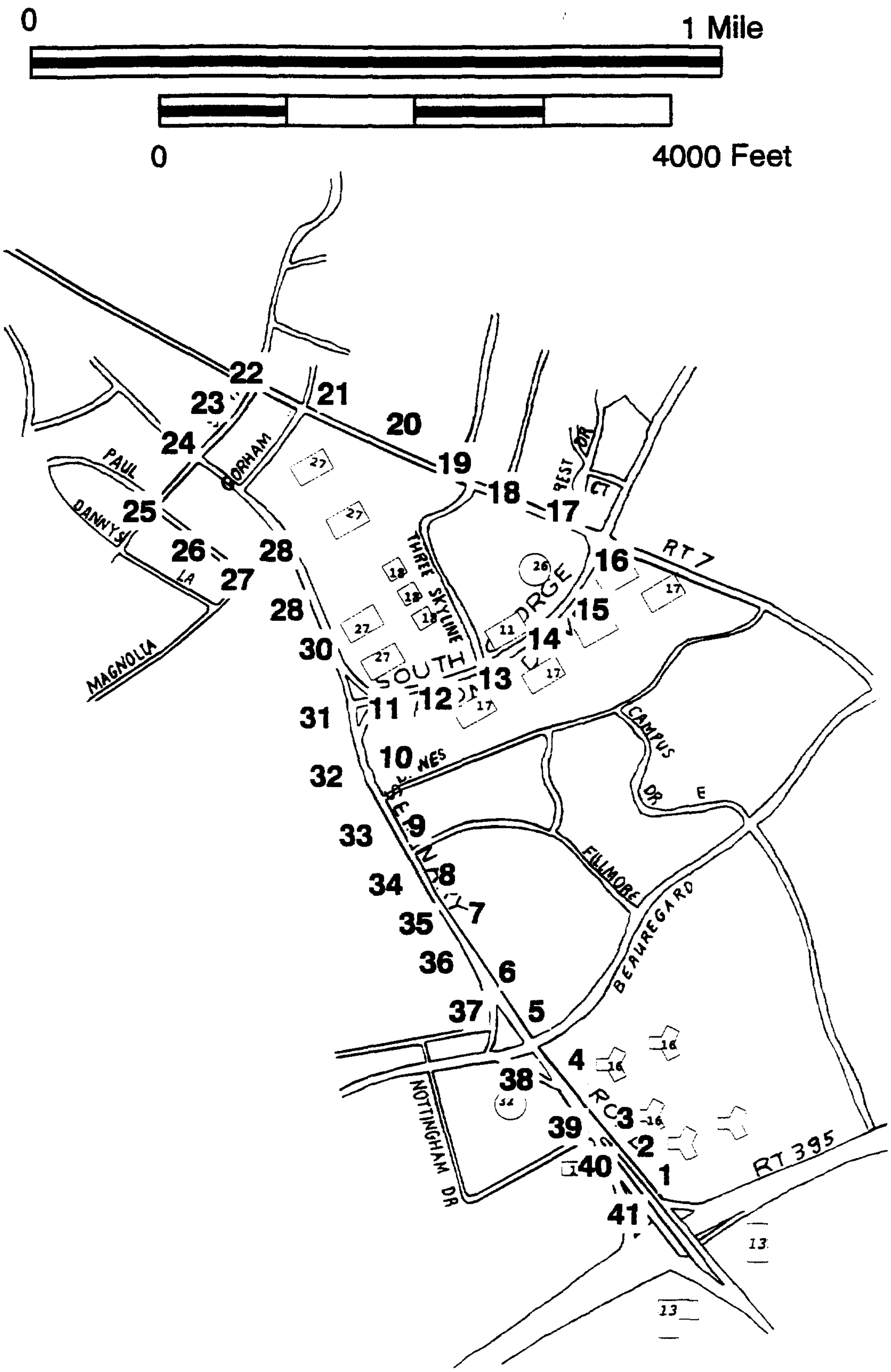


Figure A1-5 Special Range Spectrum Plot

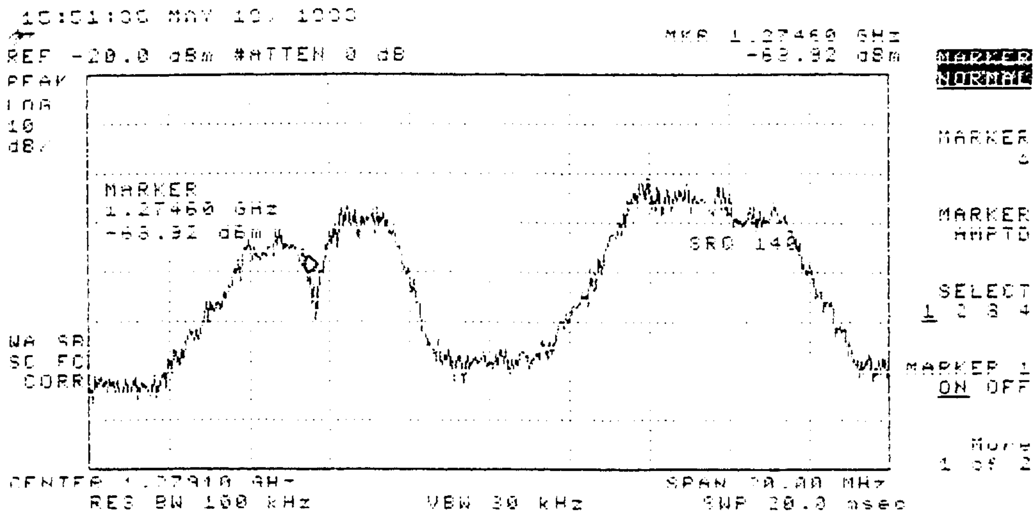


Figure A1-6 Special Range Spectrum Plot

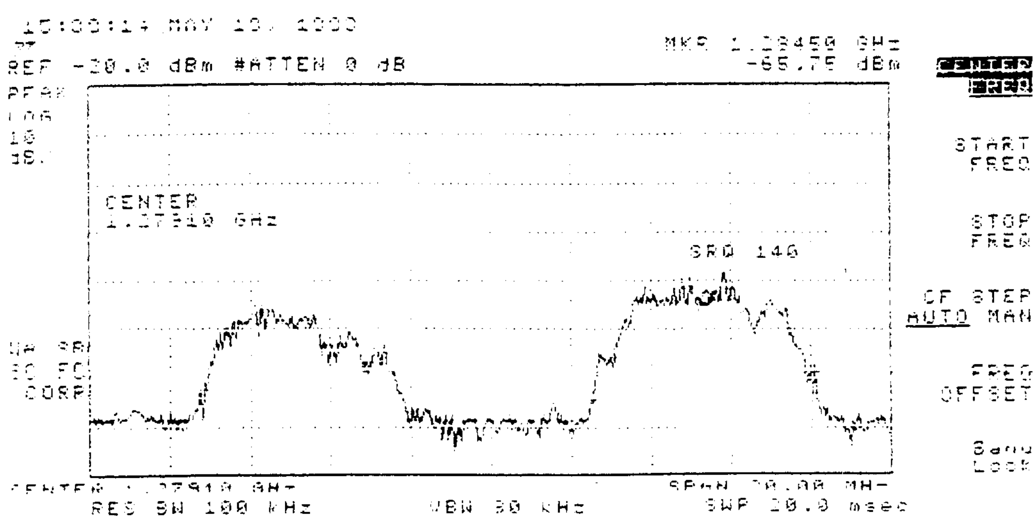
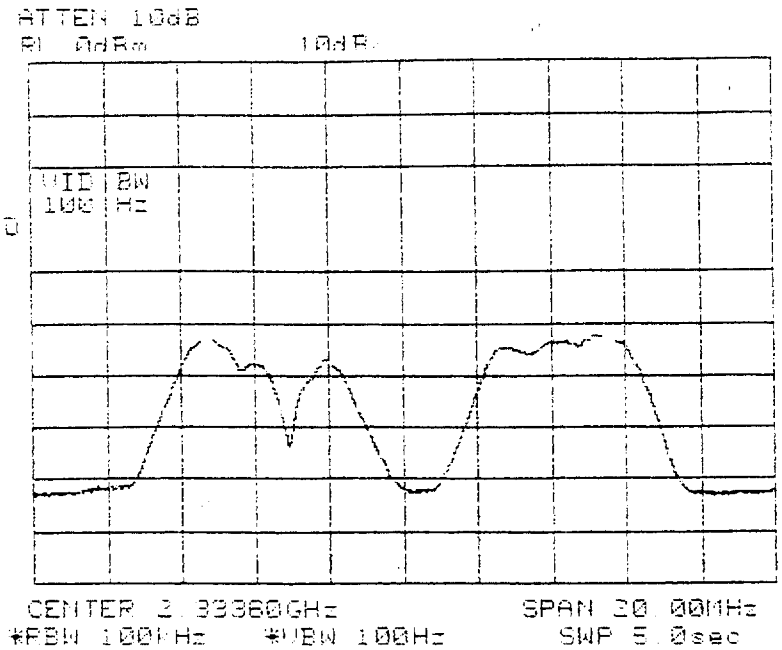


Figure A1-7 Test Range Spectrum Plot



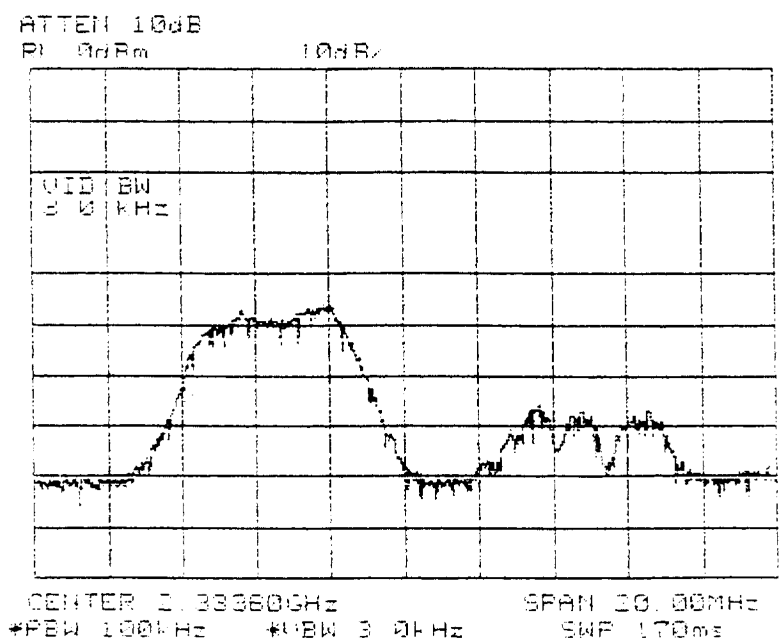
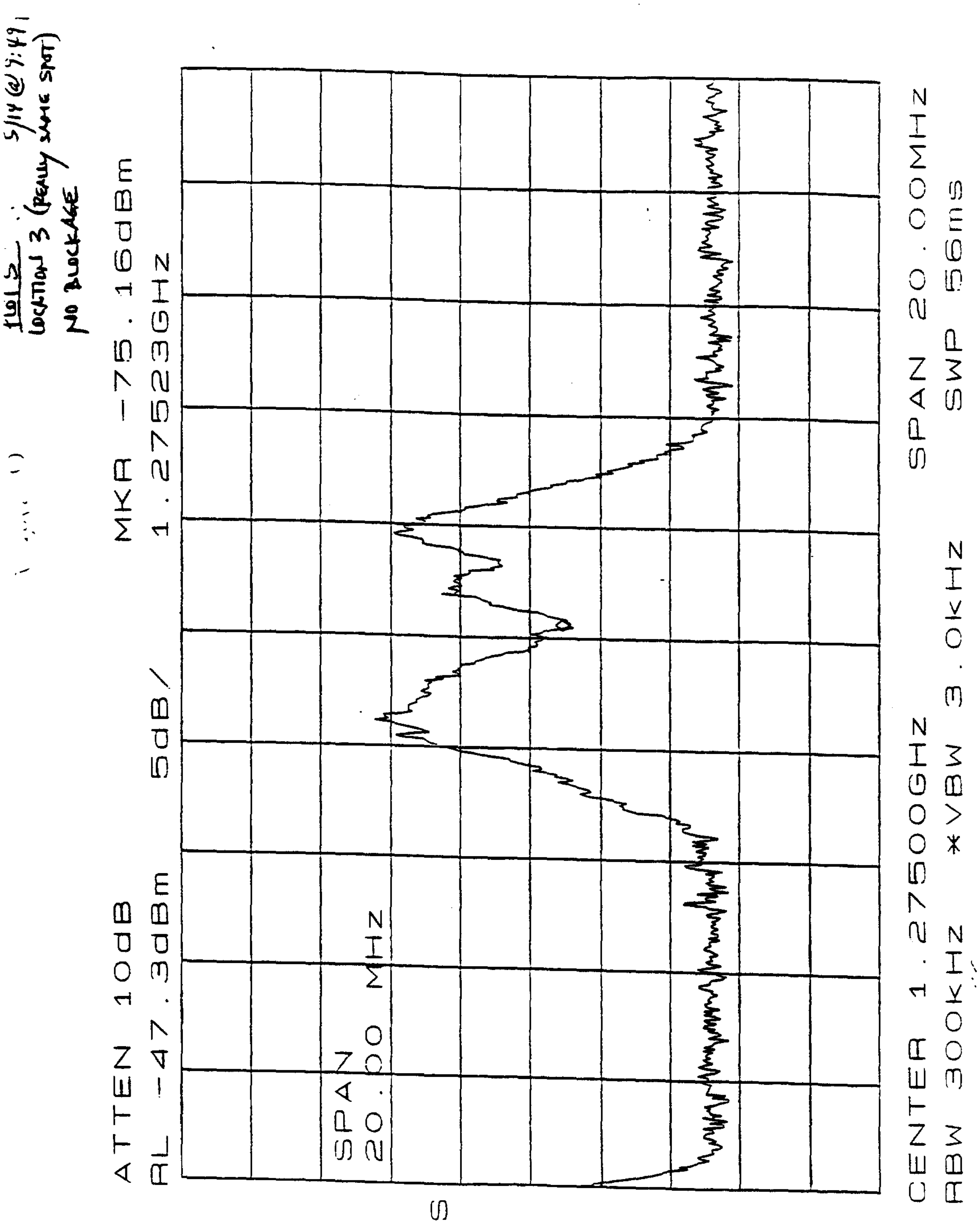


Figure A1-8 Test Range Spectrum Plot, Expanded



Results

The measurements show as seen in Figure A1-3 that the test vehicle was not blocked by any physical obstruction such as the buildings, trees, and overpasses in the Test Range due to the spatial diversity employed. The measurements also show that the combined spatial and frequency diversity mitigated multipath sufficiently that at least one receiver was always above threshold. Consequently, no loss in received signal will occur if the receiver outputs were combined or if the strongest output were selected by switching. It is noted that four transmit frequencies and receivers were used in the Test Range rather than the two frequencies to be used in the CD Radio satellite DARS system so that vehicle receiver self jamming by the closely located rooftop transmitters would be avoided. Since multipath fading often exceeded 12 dB, the measurements on the Test Range indicate mitigation of at least this amount.

Accuracy

The accuracy of the data is in the range of ± 2 dB after calibration. A portion of this is the vehicle antenna which was operated at and under 10° elevation angle as discussed in Attachment A3 paragraph A3.4. The changes in range from the vehicle to the various rooftop antennas with motion causes relatively large changes in average signal due both to the path loss variation and change in aspect angle of both vehicle and rooftop antennas. Lastly, some lip blockage by the rooftop of the transmit antenna pattern was noted and, in general, was corrected. The AGC values are non-linear.

A1.3 MOBILE RECEIVE ANTENNA

The prototype CD Radio mobile receive antenna was subjected to extensive testing. The test data show the antenna generally met all the transmission performance requirements listed in paragraph A1.4 of this report. Several important technical performance results are noted:

Effect of curved ground plane and roof depression. Extensive test data comparing the antenna mounted on a flat ground plane with the antenna mounted in a depression on a curved ground plane (surrounded and covered with auto body filler) show little difference in performance. Figure A1-9 is a conical cut at 30° elevation angle with the flat ground plane and Figure A1-10 is the same measurement made with the curved ground plane. Both ground planes have the mounting depression and auto body filler. The gains at 2.329 GHz are almost identical and the gain ripple is +/- 1.2 dB.

Operation below 20° elevation angle. As discussed in Paragraph A.1.4, the antenna was designed to operate above 20° elevation angle and, in this experiment, was frequently operated below this angle. The effects of lower elevation angle operation are shown in Figure A1-11 where the gain is reduced 5 dB and the gain ripple is increased to +/- 2.8 dB. Also, the radio frequency bandwidth is narrowed.

Installation. It is noted that the edge and surface effects of the antenna must be considered. Specifically, the material covering the antenna and holding the side surface of the disk to the depression will affect the antenna performance. The design of the antenna was optimized for the auto body filler used to cover and surround the disk. Figure A1-12 shows the deleterious effects on gain and gain ripple if this optimization is not accomplished.

Figure A1-9 CD Radio Mobile Receive Antenna, Gain, 30° Elevation, Flat Plate

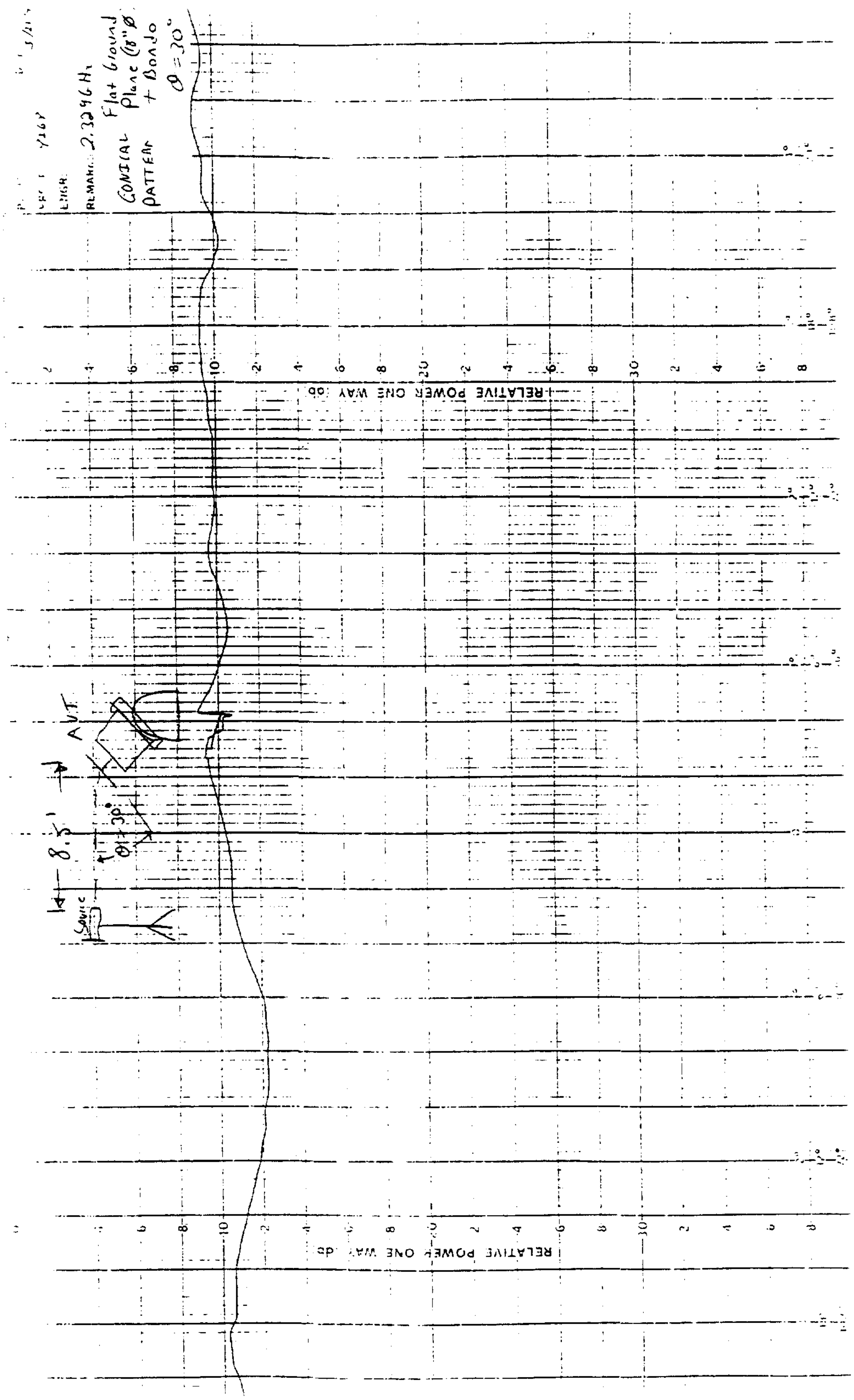


Figure A1-10 CD Radio Mobile Receive Antenna, Gain, 30° Elevation, Curved Plate

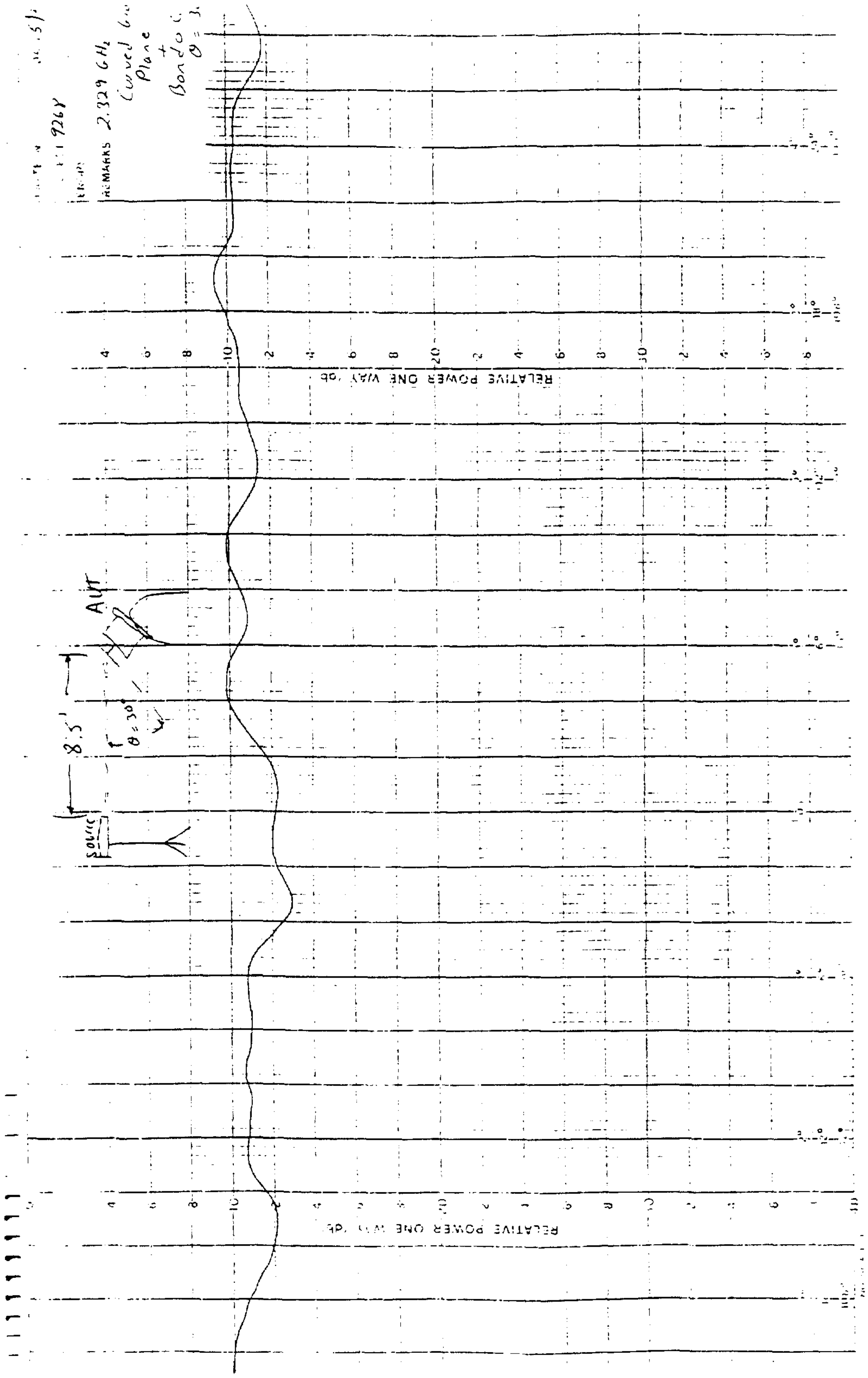


Figure A1-11 CD Radio Mobile Receive Antenna, Gain, 15° Elevation, Curved Plate with Bondo Filler

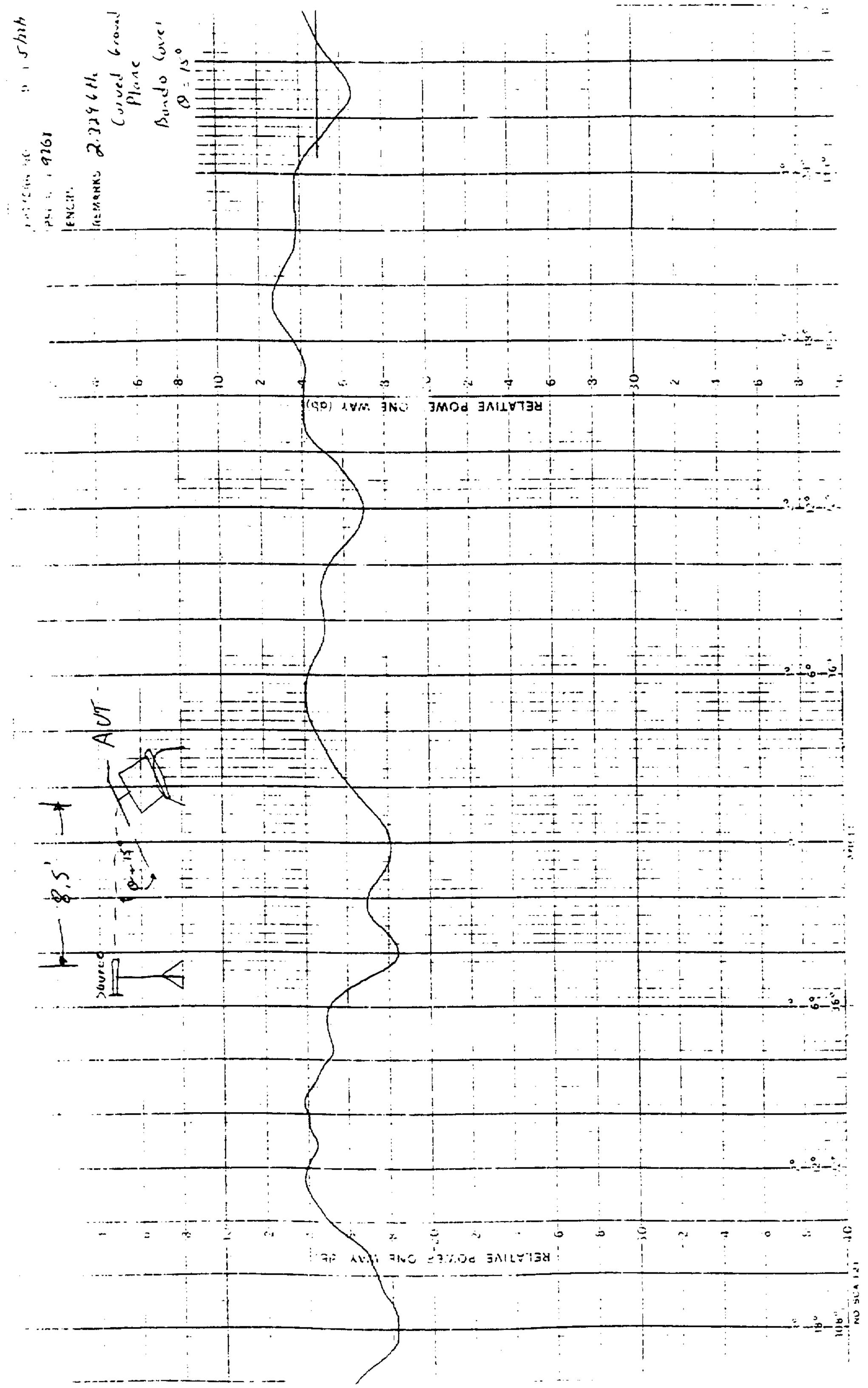
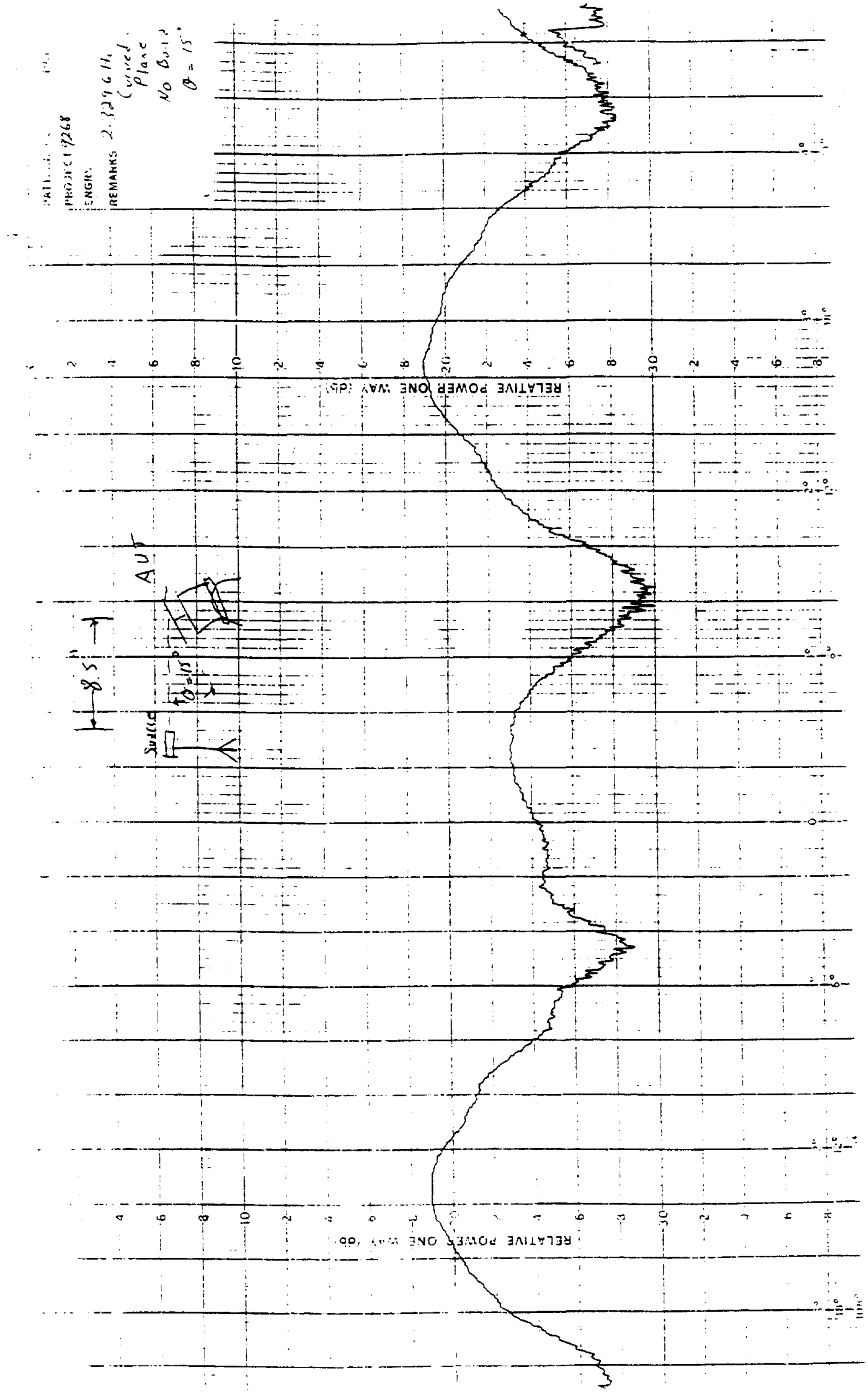


Figure A1-12 CD Radio Mobile Receive Antenna, Gain, 15° Elevation, Curved Plate without Bondo Filler



ATTACHMENT A2.

TEST RANGE

A.2.1 GENERAL DESCRIPTION

The design and implementation of the Test Range for the CD Radio satellite DARS experiment is a function of technical and real-world considerations. Technical considerations dictate that the test range closely emulate the parameters of satellite delivered DARS and incorporate features unique to the CD Radio system design. These technical considerations must be facilitated in real-world surroundings in order to investigate fully the feasibility of satellite DARS in a mobile environment. In order to satisfy the technical and real-world criteria of the experiment, a test range was designed and implemented in an urban/suburban area. The selected area is typical of a real-world mobile environment in terms of physical and associated radio frequency characteristics. The Test Range has been set up to conform to the technical requirements of satellite DARS and the unique features of the CD Radio system.

A.2.2 DESIGN

The design of the Test Range was driven by three general requirements, that it:

1. Include features typical of urban/suburban environments;

2. Provide for a path transiting that environment; and,

3. Be able to support the technical requirements of the CD Radio system architecture.

The inclusion of typical urban/suburban features in the Test Range is necessary to achieve experimental results which are transferable to a commercial satellite DARS implementation. The ability to transit that environment in a mobile vehicle is necessary for meaningful data collection. Certain requirements were imposed on the Test Range design by the experimental system architecture which were designed to emulate features unique to the CD Radio proposed system design. The Test Range design is a synthesis of these three requirements.

Features typically encountered in an urban/suburban environment include interstate highways, secondary and tertiary roads, under and over passes, varied degrees and types of foliage, fixed structures of different sizes and compositions, and open areas. Unlike areas devoid of any potential impediments, these features will present blockage and multipath problems to satellite DARS in the S-band. The CD Radio proposed system architecture incorporates several unique designs to mitigate the detrimental effects on the reception of satellite DARS signals by mobile platforms. The Test Range must incorporate these environmental features in order to explore the validity of the CD Radio system design elements which address the problems associated with the urban/suburban environment.

It was necessary to traverse the Test Range area with a mobile vehicle in order to gather experimental data from different positions relative to the transmission sites. It was also desirable to have a test route loop of at least 2 miles with a 5 to 10 minute traverse time. A test route loop of significant distance contributes both to the number of environmental scenarios encountered and permits repeatability of the results for more accurate data analysis. It was necessary for the Test Range to have sufficient access for the mobile vehicle around the Test Range in order to increase the potential for data gathering.

Several locations around the Washington metropolitan area were identified which incorporated the typical urban/suburban features and mobility around the proposed Test Range. Locations which were identified as meeting CD Radio criteria were then assessed against the technical requirements of the experimental system. The technical requirements of the experimental system necessitated the existence of tall fixed structures from which to transmit the emulated satellite DARS signal from the transponders at S-band. Further, these structures had to be located relatively close to each other within the Test Range so as to provide coverage patterns congruent with the investigation of frequency and space diversity for multipath mitigation.

One requirement for the individual transmitter sites is that the rooftop be tall enough to provide a 10°-60° elevation angle from some section of the mobile test route. A 20°-60° elevation angle from the mobile vehicle is within the optimum parameters of the small, low gain omni-directional antenna which is part of the proposed CD Radio system. Table A2-1 shows a range of building heights and associated minimum and maximum distances from the S-band transmitter sites for the desired 10°-60° elevation angles from the mobile receiver and the effective coverage area. This information was used in a determination of potential Test Range sites as well as suitability of buildings within those sites for transponder locations. From Table A2-1 it was determined that it was most efficient to select buildings greater than ten (10) stories in height. This results in an individual building coverage area of at least 0.1 mi^2.

Working as a system, the combination of the transmitter sites must cover all of the Test Range route at approximate 10°-60° elevation angles from the mobile vehicle with overlapping coverage provided by at least two sites. The overlapping coverage is necessary to provide space and frequency diversity along the test route. The space and frequency diversity is unique to the CD Radio proposed system architecture and is designed to mitigate fading and blockage.

A location in Arlington, Virginia was preliminarily selected as the Test Range. The Test Range is an area generally along Seminary Road bounded by Interstate-395 on the east and Gorham Road on the west. Seminary Road runs from southeast to northwest connecting I-395 and Gorham Road. South George Mason Drive and Leesburg Pike are incorporated into the Test Range. The route around the proposed Test Range loop would be approximately 3.5 miles in length and variable as to path. A map of the general area of the Test Range is shown in Figure A2-1.

Figure A2-1 Road Map, Test Range Area

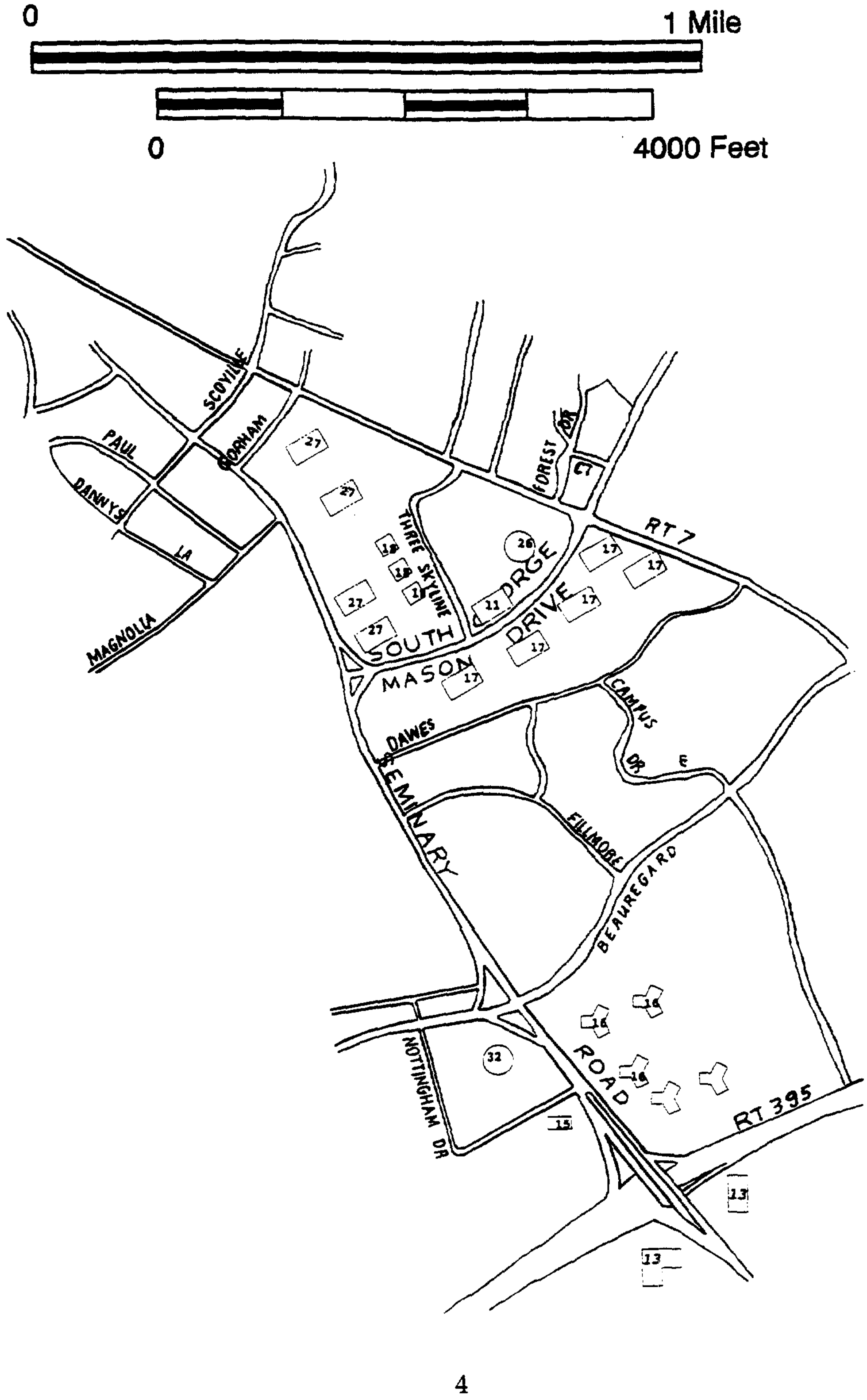


Table A2-1 Range of Building Heights and associated Coverage Area

TABLE A2-1: Range of Building Heights and Associated Coverage Areas (Height and Distance in Feet)

Number of Building Floors	Building Height	Antenna Height With Mast	Maximum Distance From Building for 10° Elev. From Mobile	Distance From Building for 20° Elev. From Mobile	Minimum Distance From Building for 60° Elev. From Mobile	Effective Coverage Area Given 100 Foot Building Set-Back (sq. mi.)
5	50	70	397	192	40	0.02
10	100	120	681	330	69	0.05
15	150	170	964	467	98	0.10
20	200	220	1,248	604	127	0.17
30	300	320	1,815	879	185	0.37
35	350	370	2,098	1,017	214	0.49

usable building heights based on effective coverage area

The Seminary Road Test Range location provided a combination of typical urban/suburban features and tall buildings with acceptable spatial relationships. Urban features in the Test Range included an interstate highway and underpass, secondary roads and neighborhoods, a pedestrian overpass, varying degrees and types of foliage, and buildings ranging in height from one to thirty-two stories. From the information shown in Table A2-1, there were a sufficient number of buildings within the height range to provide the necessary elevation angles from the mobile vehicle. Vehicular access to and around the proposed Test Range also appeared to be sufficient for the experiment.

After the preliminary selection, the proposed Test Range was evaluated for appropriateness based on building height and location and the coverage patterns of the transmission of the emulated signal from the roof-top transponders. Known information regarding the coverage patterns for the S-band antenna type, transmit power level, and building elevation were applied to an aerial view of the Test Range. Utilizing the aerial view of the area with building roof elevation information, sites were chosen that would appear to provide the appropriate coverage patterns.

Table A2-2 relates the coverage areas of targeted transponder locations based on S-band transmit antenna height. The effective coverage areas of the targeted buildings range from 0.1 to 0.4 mi^2. This allowed a determination of Test Range efficacy and aided in the selection of building roof-tops for transponder placement. Figure A2-2 shows the coverage area information applied to the aerial view of the Test Range. The coverage areas and consequent desired overlap can be discerned from the view in Figure A2-2. Figures A2-3 and A2-4 are photographs of the Test Range area from transponder sites E and F (as identified in Figure A2-2), respectively.

The application of the technical parameters of the CD Radio experimental system to the proposed Test Range showed that the Seminary Road site was suitable for the satellite-DARS experiment. The site satisfied the conditions of: 1.) urban/suburban environment, 2.) ability to drive around the environment and, 3.) support of the experimental system

TABLE A2-2: Selected Buildings and Associated Coverage Areas (Height and Distance in Feet)

Number of Building Floors	Building Height	Antenna Height With Mast	Maximum Distance From Building for 10° Elev. From Mobile	Distance From Building for 20° Elev. From Mobile	Minimum Distance From Building for 60° Elev. From Mobile	Effective Coverage Area Given 100 Foot Building Set-Back (sq. mi.)
15	150	170	964	467	98	0.10
16	160	180	1,021	495	104	0.12
27	270	290	1,645	797	167	0.30
28	280	300	1,701	824	173	0.32
33	330	350	1,985	962	202	0.44

acquired building's heights

Figure A2-2 Test Range Road Map

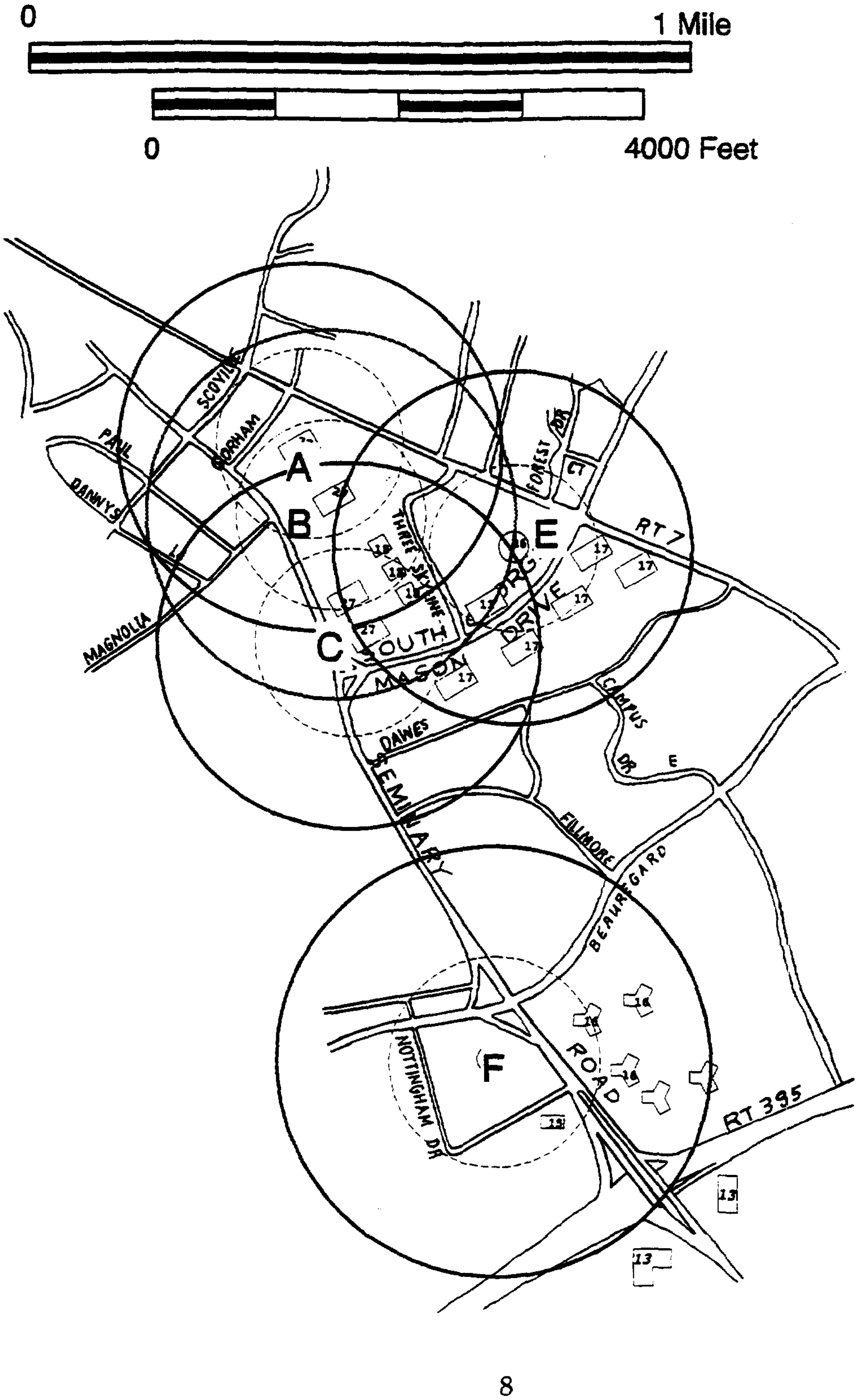


Figure A2-3 Test Range Area, View From Site E

Figure A2-4 Test Range Area, View From Site F

architecture technical requirements. After selection of the Test Range site it was necessary to implement the experimental system within the range and according to the design devised from the aerial view.

A.2.3 IMPLEMENTATION

The implementation of the designed Test Range was in three stages:

1. Building roof-top lease acquisition;

2. Transponder equipment installation; and,

3. Alignment, tuning, and verification of predicted coverage patterns.

The satisfaction of these three stages was a prerequisite to the operation of the experimental system.

The roof-top leases secured permission from the owners of the target buildings to install the equipment. The leases are composed of six general clauses: 1.) monthly cost for the roof-top space, 2.) duration of the lease, 3.) liability for damages information, 4.) definition of the equipment to be installed on the roof-top, 5.) definition of access times and procedures for the roof area and, 6.) included services. Similar leases are in wide-spread use for the installation and operation of communications antennas. Several of the target sites in the Test Range area are lessors of communications antenna space and were familiar with the procedures. Other targeted sites were unfamiliar with the procedures for leasing roof-top space which extended the time required to formalize the agreement.

Leases were secured with five building owners in the Seminary Road Test Range area. These buildings enable coverage of the Test Range area exclusive of the I-395 overpass. Initial benchmark data on overpass blockage and the mitigation of that blockage through spatial diversity was collected at the Crystal City test site. This site offered a more controlled environment for the collection of the initial overpass data due to fewer